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Herpetofauna inside and outside from a natural protected area: the case of Reserva Estatal de la Biósfera Sierra San Juan, Nayarit, Mexico

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Abstract

Natural Protected Areas (NPAs) includes important species richness, and it is assumed that these are the best areas for biodiversity conservation. There are certain doubts, however, about the effectiveness of the NPAs in developing countries, where economic resources for conservation are scarce and NPAs are not monitored and managed efficiently. In the present study we assessed the species richness, diversity, abundance, and functional guilds of amphibians and reptiles inside and outside of the NPA Reserva Estatal de la Biósfera Sierra San Juan (REBSSJ), Nayarit, Mexico. Our results showed that species numbers of amphibian and reptiles were higher outside than inside the reserve, as well the individual number distributed among species, except for lizard species. Analyses of functional guilds showed that both richness and functional dispersion were greater in amphibians and reptiles outside the reserve. Likewise, outside the reserve we recorded a higher species number with some category of risk at the national level (NOM-059), international level (IUCN), and also by using the Environmental Vulnerability Score (EVS) algorithm. The results suggest that areas outside of the reserve are crucial to the maintenance of regional biodiversity, due to high complementarity with species composition inside of the reserves. These data can be used to implement conservation measures that include a new demarcation of the reserve and the consideration of surrounding areas to include a great number of species.

Keywords
Amphibians, abundance, conservation, diversity, natural protected area, reptiles

Introduction

Worldwide, the creation of Natural Protected Areas (NPAs) has been one of the major measures to conserve biodiversity (Rodrigues et al. 2004). Under certain scenarios, however, it has been found that parks may not be the optimal governance structure for promoting local conservation, primarily because economic and human resources are scarce (Hayes 2006) and such areas become only paper parks (Rife et al. 2013, Blackman et al. 2015). Mexico has 182 NPAs decreed under different categories, such as national parks, biosphere reserves, and natural monuments, among others (CONANP 2017).

In spite of the high number of NPAs registered currently, most of them have been established in an arbitrary way, because in most cases there is a lack of basic biological information of the species that are in these areas (Ervin 2003). As such, it is important to assess the efficiency of the decreed NPAs, because in most cases not all components of the biodiversity are preserved, e.g., species, vegetation types, ecosystems, homogeneity, and heterogeneity (Chape et al. 2005). On the other hand, these areas are damaged by anthropic effects, such as illegal looting of flora and fauna, pollution, deforestation, landscape fragmentation, and land-use change (Ervin 2003, Figueroa and Sánchez-Cordero 2008). This disturbance has been consistently evident in tropical areas of developing countries (Román-Cuesta and Martínez-Villalta 2006, Urbina-Cardona et al. 2006). For example, in Sierra San Juan, in Nayarit, Mexico there is a Reserva Estatal de la Biosfera Sierra San Juan (REBSSJ), which was declared in 1987 with the objective to stop the exploitation of banks of materials (González 2010). At the time of being declared as an NPA, however, government officials did not have available accurate information on diversity and abundance of the species, as well as the values of elements of biodiversity of landscape or the most outstanding natural processes; instead, it used as a criterion for its delimitation surface which is comprised up of 980 m a.s.l. (González 2010).

The REBSSJ is located at the westernmost extreme of the Mexican Transvolcanic Belt, in Sierra San Juan, which constitutes a geomorphological unit separated of this biogeographic province (Luhr 2000). Due to this isolation, the study of biological diversity in the REBSSJ is very interesting because it illustrates several vegetation types, which are semi-deciduous tropical forest, cloud forest, oak forest, pine forest, oak-pine forest, and secondary scrubland (Téllez 1995). In this area, there are at least 1250 species of plants and ferns (30% of the flora reported for Nayarit), of which 31 are endemic to Mexico (Téllez 1995), and at least 370 species of birds (44.9% reported from Nayarit; Espinosa 2000).

The amphibians and reptiles from this region have been poorly studied. The only previous study for the site is a catalogue of the species of this group by Bojórquez (2003). In this work, 36 species were reported from Sierra San Juan and 12 for the REBSSJ. In this catalogue is included the Mexican Spiny-tailed Iguana (*Ctenosaura acanthura*) and Tehuantepec Striped Snake (*Geagras redimitus*). Natural distribution of these species occurs quite far from REBSSJ, because the former species occurs in states bordering the Gulf of Mexico and the latter in the southeastern portion of the country (Ramírez-Bautista and Hernández-Ibarra 2004, Canseco-Márquez 2007); therefore, these two species suggest an erroneous of species identification from REBSSJ. Recently, Woolrich-Piña et al. (2016) published an article on the herpetofauna of Nayarit, in which they included a limited analysis of diversity in NPAs including REBSSJ. This revision was made based on literature reviews and opportunistic fieldwork only, so the authors did not conduct systematic fieldwork and the data presented on this paper concerning the REBSSJ should be taken with caution.

In order to assess the effectiveness of this NPA, the objectives of this study are: (i) to determine species richness, abundance, functional richness, functional equality, and functional dispersion of amphibians and reptiles inside and outside of the REBSSJ, and (ii) to compare diversity patterns inside and outside of the REBSSJ. This work is important because in spite of being a protected area, diverse anthropic activities are conducted within its boundaries, such as coffee and avocado cultivation, without supervised regulation or estimation of the impact on biodiversity. Thus our hypothesis of work is that because the natural protected area is surrounded by zones highly transformed; therefore there will be a different number of species and communities composition of amphibians and reptiles, with low number of species outside of reserve.

Methods

Study Area

The study area is located in Sierra San Juan in the central portion of the state of Nayarit, and comprises part of the municipalities of Tepic, Xalisco, and San Blas (21°20'–21°32'N; 104°53'–105°03'W; datum WGS84; Figure 1). Elevations in the sierra range from 400 to 2250 m. The climate according to Köppen classification, as modified by García (1988), is semi-arid and temperate. A semi-warm climate also exists, at elevations of 1200 m., with a temperature from 18°C to 22°C. On the other hand, temperate regions presents mean annual temperatures from 15.5°C to 18°C at an elevation of 1200 m. Mean annual precipitation varies between 1100 and 1700 mm, which occurs from June to October. Vegetation types of the Sierra San Juan are oak forest, oak-pine forest, and patches of cloud forest (Téllez 1995). Outside of the reserve, vegetation type has been modified by anthropic effects, and it is avocado cultivation (east zone) and mango cultivation (west zone), with patches of semi-deciduous tropical forest, and less extension of cloud forest,

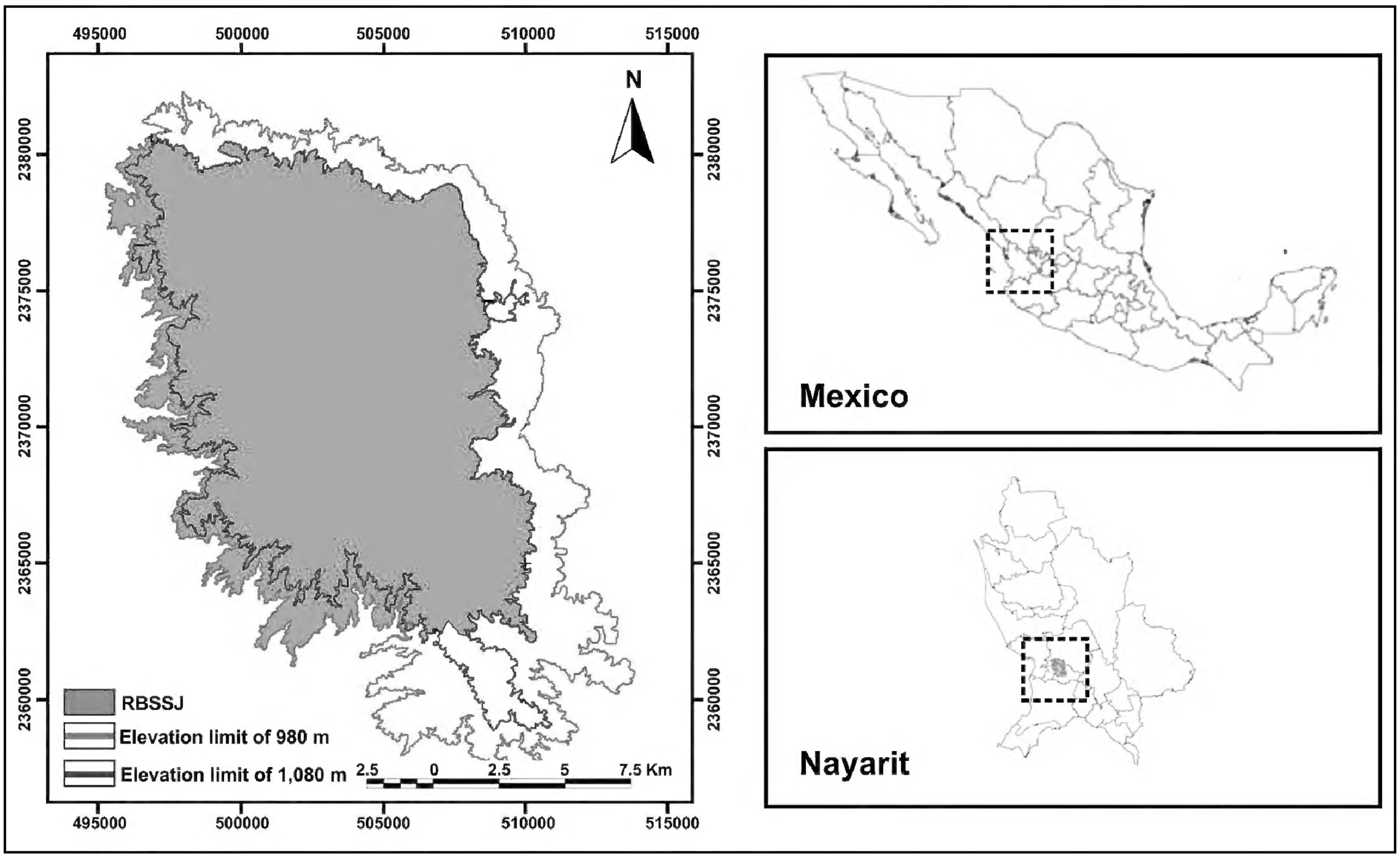

Figure 1. Location of the Reserva Estatal de la Biósfera Sierra de San Juan (REBSSJ) in the Sierra San Juan Nayarit, Mexico. Modified from González (2010).

which is a strip that is located between 700 and 1200 m of elevation, which is devoted to coffee plantation under shade.

Fieldwork

This study was carried out between June 2012 and August 2015. Surveys were conducted during each month in a systematic way by dedicating a whole day of sampling for searching the amphibians and reptiles inside and outside of the reserve. For each day, random surveys of the specimens were made by two people, which began from 09:00 to 14:00 h, and from 17:00 to 22:00 h (10 h/man by 2 persons = 20 man hours). Total sampling was an effort of 1520 man-hours equally distributed inside and outside of the reserve (760 h/man each one). Amphibians and reptiles were searched for during the hikes by checking all habitats and microhabitats types, such as under rocks and logs and within litter, holes, and crevices (Casas-Andreu et al. 1991). In order to avoid pseudoreplication we did not sample in the same site more than a single time (Luja et al. 2008). The first five specimens each species observed in the field were collected by hand or herpetological hooks in case of individuals of genus *Crotalus*, to be identified based on our experience or with dichotomous keys, and each specimen was photographed, which photographs were housed at Texas University in Arlington (UTADC). In this study we followed the taxonomy by Wilson et al. (2013a, b).

Data analysis

In order to estimate the completeness of the inventory of the amphibians and reptiles from inside and outside the reserve, we constructed a species accumulation curve (Moreno 2001) using the program ESTIMATES ver. 750 (Colwell 2005). Because the analysis was performed by using abundance of the species, we used the non-parametric estimators ACE and Chao 1 (Jiménez-Valverde and Hortal 2003); in addition, we used logarithms that assess species that were represented in samples by 1 (singletons) or 2 (doubletons) individuals (Colwell and Coddington 1994).

Species diversity of amphibians and reptiles was assessed inside and outside of the reserve by effective species number according to the method proposed by Jost (2006). For this analysis we took into consideration the order q = 1, it considers proportional abundance of each species (Jost 2006). The equation is represented as $^1D = \exp(H')$, where ^1D is the true diversity, and exp (H') is the Shannon exponential index (Jost 2006, Moreno et al. 2011). On the other hand, we compared species richness between sites considering the abundance of the individuals by rarefaction curves (Gotelli and Colwell 2001). These curves were generated by the program PAST (Hammer et al. 2001). In addition, to assess the abundance and equity of amphibians and reptiles inside and outside of the reserve we performed curves of rank-abundance (Magurran 1998, Feinsinger 2003) by using species number and individuals per species recorded in the study area. The curves were graphed according to logarithm of proportion of each species p(n/N), and the data is sorted from the most abundant species to the least abundant.

To assess beta diversity between areas we used the complementarity index (Colwell and Coddington 1994). For this analysis we related the number of species of site A to the number of species of site B, and the number of species in common between A and B (Colwell and Coddington 1994). Therefore, in this way we obtained the species richness for both communities by the formula $SAB = a + b - c$, where a is the species number of the site A, b is the species number of species in the site B, and c is the number of species in common between sites A and B. Exclusive species number (U) for any place is represented as $UAB = a + b - 2c$, and with these values, the complementarity (C) between both places was calculated as $CAB = U\,AB/SAB$. Complementarity values vary from 0 when both places are identical in their composition to 1 when species of both places are different (Colwell and Coddington 1994).

Finally, to assess the functional diversity (FD) we collected information (on literature and databases) about four specific traits: i) Habits (terrestrial, arboreal, terrestrial semi arboreal and terrestrial freshwater), ii) Diet (insects, insects and small mammals, insects and vegetables, small mammals, lizards and rodents, amphibians, small rodents, amphibians and lizards, lizards and snakes, lizards and small mammals, fish and aquatic insects), iii) Activity (diurnal, nocturnal, diurnal and nocturnal), and iv) Foraging mode (active or sit-and-wait). To obtain the values of FD, three measures as response variables were calculated using multivariate methods, one that uses information presence or absence of each species (functional richness, Fr), and two measures that incor-

porate information on the abundance of species (functional equity, Fe) and functional dispersion (Fd). This method was chosen because functional characterization of the assemblage is achieved by considering jointly these three components (Mason et al. 2005, Villéger et al. 2008), hence its classification as multidimensional indices that are based on the profile of the traits of each species (Laliberté and Legendre 2010). Functional Diversity indices were calculated based on the Gower distance using the software FDIVERSITY (Casanoves et al. 2011).

Results

Herpetofauna from Sierra San Juan

Species composition of the Sierra San Juan is 55 in total. Five families, 10 genera, and 15 species represent amphibians, whereas reptiles are represented by 18 families, 32 genera, and 40 species (Table 1). Among amphibians, the family Hylidae was the most diverse, with 5 species; Craugastoridae contained four species, while Bufonidae, Eleutherodactylidae, and Ranidae each contain two species. Two turtle species are represented by one family each, Geoemydidae and Kinosternidae, and one genus in each (Table 1). Lizard species were represented among eight families, nine genera, and 14 species. The family Phrynosomatidae was represented by six species, Teiidae with two, and the families Anguidae, Dactyloidae, Gekkonidae, Helodermatidae, Iguanidae, and Scincidae were represented by one species each (Table 1). Finally, snake species are represented by eight families and 21 genera, which are Boidae, Colubridae, Dipsadidae, Elapidae, Leptotyphlopidae, Natricidae, Typhlopidae, and Viperidae (Table 1).

Herpetofauna inside REBSSJ

In this area was carried out 39 samplings, in which we recorded 34 species (seven amphibians and 27 reptiles; Table 1). The amphibian species belong to four families (Craugastoridae, Eleutherodactylidae, Hylidae, and Ranidae) and four genera. Among reptiles we recorded two turtle species (*Rhinoclemmys pulcherrima* and *Kinosternon integrum*), 11 lizards, and 14 snake species, with the families Colubridae and Dipsadidae the most diverse in species, with 10 and 15, respectively (Table 1).

Species accumulation curves, completeness of the inventory and abundance of amphibians and reptiles inside of REBSSJ

In this area we recorded a total of seven amphibian species. The ACE and Chao 1 estimators predicted seven species each (Figure 2a); therefore, we obtained a completeness of 100%. On the other hand, we recorded in this reserve 27 species of reptiles, and

Table 1. List of species of amphibians and reptiles of Sierra San Juan, Nayarit, and Biosphere Reserve Sierra San Juan (RBSSJ) (X = occurrence). The code of each species used in the curves of rank-abundance (Code) is provided. Also, E = endemic to Mexico, protection category according to the Mexican Official Standard NOM-059 (Pr = Special protection, A = endangered), and International Union for Conservation of Nature (IUCN, Lc = Leas Concern, Dd = Deficient data, V = Vulnerable, NT = Near Threatened, NC = Not Consider), are provided. The population status (STAT POP; S = Stable, I = Increasing, U = Unknown, D = Decreasing, NC = Not Consider) and the value of environmental vulnerability index according to Wilson et al. (2013a, b) (EVS for its acronym in English; L = low [3-9], M = medium [10-13], H = high [14-20]; ?= not tested) are shown.

Species	Code	Endemism	NOM-059	IUCN	STAT POP	EVS	Inside RBSSJ	Outside RBSSJ
Class Amphibia								
Order Anura								
Family Bufonidae								
Incilius mazatlanensis	1	E		Lc	S	12 (M)		X
Rhinella marina	2			Lc	I	3 (L)		X
Family Craugastoridae								
Craugastor augusti	3			Lc	S	8 (L)	X	
C. occidentalis	4	E		DD	U	13 (M)	X	X
C. pygmaeus	5			Vu	D	9 (L)	X	X
C. vocalis	6	E		Lc	D	13 (M)		X
Family Eleutherodactylidae								
Eleutherodactylus nitidus	7	E		Lc	S	12 (M)	X	X
E. pallidus	8	E	Pr	DD	U	17 (H)	X	X
Family Hylidae								
Agalychnis dacnicolor	9	E		Lc	S	13 (M)		X
Exerodonta smaragdina	10	E	Pr	Lc	S	12 (M)		X
Sarcohyla bistincta	11	E	Pr	Lc	D	9 (L)	X	X
Smilisca baudinii	12			Lc	S	3 (L)		X
Tlalocohyla smithii	13	E		Lc	D	11 (M)		X
Family Ranidae								
Lithobates magnaocularis	14	E		Lc	U	12 (M)	X	X
L. pustulosus	15	E	Pr	Lc	S	9 (L)		X
Class Reptilia								
Order Testudines								
Family Geoemydidae								
Rhinoclemmys pulcherrima	16		A	NC	NC	8 (L)	X	X
Family Kinosternidae								
Kinosternon integrum	17	E	Pr	Lc	S	11 (M)	X	X
Order Squamata								
Family Anguidae								
Elgaria kingii	18		Pr	Lc	S	10 (M)	X	X
Family Dactyloidae								
Anolis nebulosus	19	E		Lc	S	13 (M)	X	X
Family Gekkonidae								
Hemidactylus frenatus	20			Lc	S		X	X
Family Helodermatidae								
Heloderma horridum	21		A	Lc	D	11 (M)	X	

Species	Code	Endemism	NOM-059	IUCN	STAT POP	EVS	Inside RBSSJ	Outside RBSSJ
Family Iguanidae								
Ctenosaura pectinata	22	E	A	NC	NC	15 (H)		X
Family Phrynosomatidae								
Sceloporus asper	23	E	Pr	Lc	D	14 (H)	X	X
S. horridus	24	E		Lc	S	11 (M)		X
S. melanorhinus	25			Lc	S	9 (L)		X
S. torquatus	26			Lc	S	11 (M)	X	
S. unicanthalis	27	E		NC	NC	?	X	
S. utiformis	28	E		Lc	S	15 (H)	X	X
Family Scincidae								
Plestiodon sp	29	E		NC	NC	?	X	X
Family Teiidae								
Aspidoscelis costata	30	E	Pr	NC	NC	11 (M)	X	X
Holcosus sinister	31			NC	NC	?	X	X
Family Boidae								
Boa sigma	32	E	A	NC	NC	10 (M)	X	X
Family Colubridae								
Coluber mentovarius	33			Lc	U	6 (L)		X
Drymarchon melanurus	34			Lc	S	6 (L)	X	X
Drymobius margaritiferus	35			NC	NC	6 (L)		X
Lampropeltis triangulum	36		A	NC	NC	7 (L)	X	X
Leptophis diplotropis	37	E	A	Lc	S	14 (H)		X
Mastigodryas melanolomus	38			Lc	S	6 (L)	X	X
Oxybelis aeneus	39			NC	NC	5 (L)		X
Senticolis triaspis	40			Lc	S	6 (L)		X
Tantilla calamarina	41	E	Pr	Lc	S	12 (M)		X
Trimorphodon tau	42			Lc	S	13 (M)	X	X
Family Dipsadidae								
Geophis dugesii	43			Lc	U	13 (M)	X	
Leptodeira splendida	44	E		Lc	U	14 (H)		X
Rhadinaea hesperia	45	E	Pr	Lc	S	10 (M)	X	X
R. taeniata	46	E		Lc	S	13 (M)	X	X
Sibon nebulatus	47			NC	NC	5 (L)		X
Family Elapidae								
Micrurus distans	48	E	Pr	Lc	S	14 (H)	X	
M. proximans	49	E	Pr	Lc	U	18 (H)	X	X
Family Leptotyphlopidae								
Rena humilis	50			Lc	S	8 (L)	X	X
Family Natricidae								
Storeria storerioides	51	E		Lc	S	11 (M)	X	
Family Typhlopidae								
Indotyphlops braminus	52			NC	NC	?		X
Family Viperidae								
Agkistrodon bilineatus	53		Pr	NT	D	11 (M)		X
Crotalus basiliscus	54	E	Pr	Lc	S	16 (H)	X	X
C. campbelli	55	E		NC	NC	?	X	

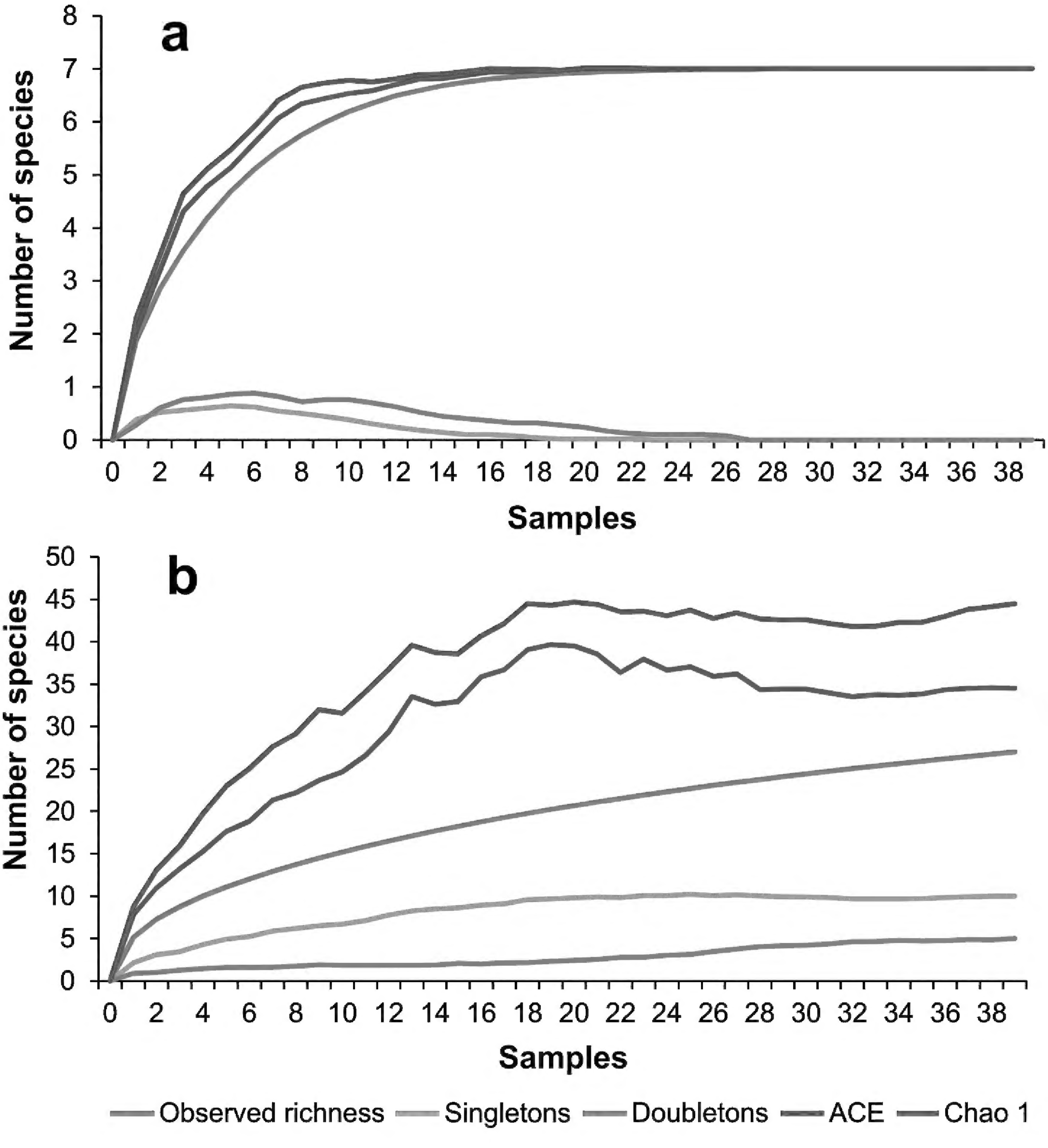

Figure 2. Species-accumulation curve for amphibians (**a**) and reptiles (**b**) inside of REBSSJ. Observed richness, species represented by a single individual (singletons), species with two individuals (doubletons), and estimated species (ACE and Chao 1).

both estimators predicted 44 and 36 species, respectively (Figure 2b), with a completeness of 60.7 and 72.9%. According to estimators, it is expected to record between nine and 17 species for achieving to the asymptote and completeness of the inventory (Figure 2b).

According to abundance, for amphibians, rank–abundance curves indicated that the dominant species inside of the reserve was *Craugastor occidentalis*, and the species with less dominance was *C. augusti* (Figure 3a). Among reptiles, the analysis was divided into lizards and snakes. Rank–abundance curves showed that *Anolis nebulosus* was the most abundant species, and the least abundant were *Sceloporus utiformis* and *S. asper* (Figure 3b). Three

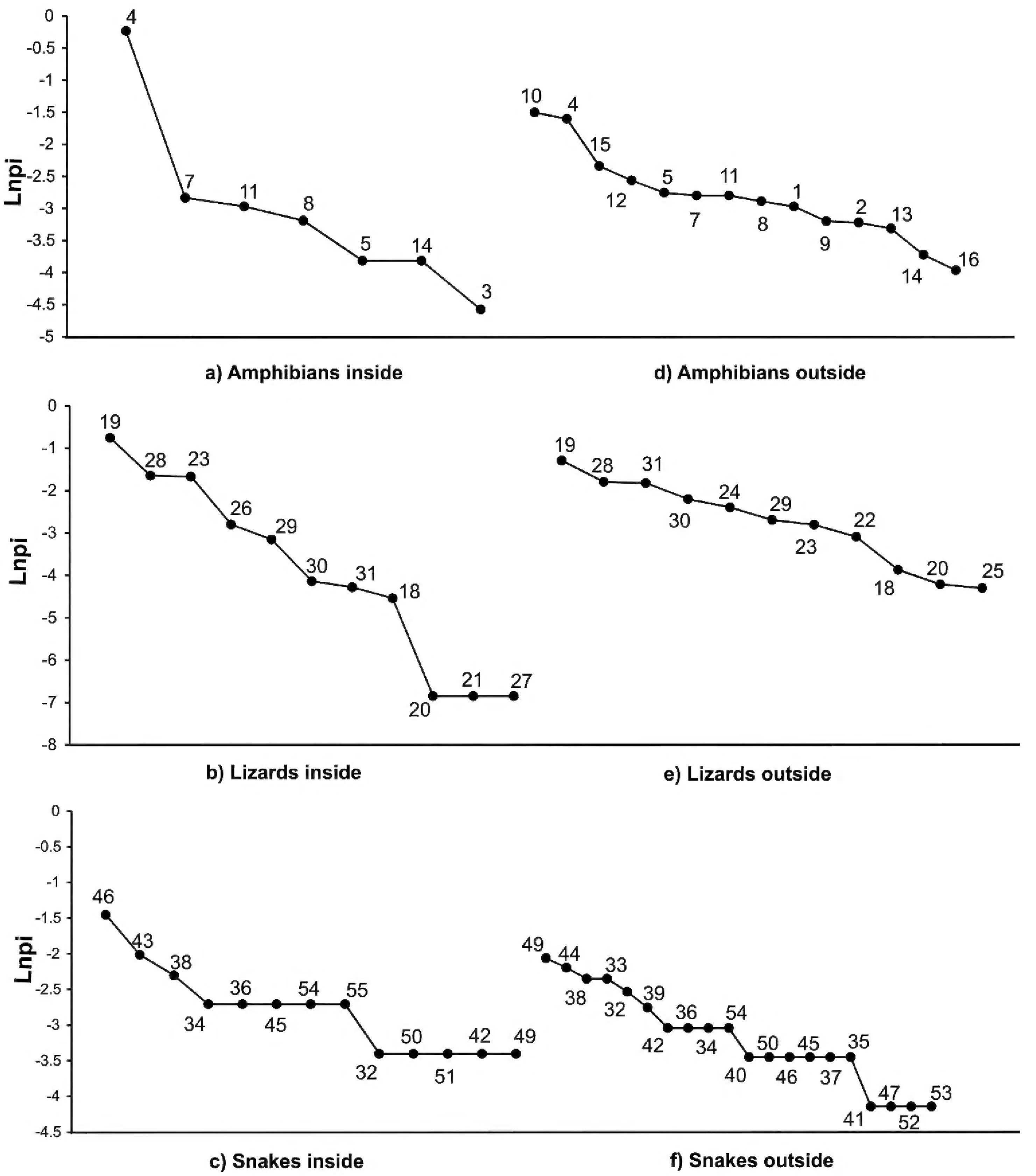

Figure 3. Rank-abundance curves for species of amphibians, lizards, and snakes inside (**a, b, c**), and outside (**d, e, f**) of the REBSSJ. Numbers refers to the acronyms of the species listed in Table 1.

species, *Hemidactylus frenatus*, *Heloderma horridum*, and *S. unicanthalis* were represented by one individual (Figure 3b). Among snakes, *Rhadinaea taeniata* was the most abundant species, while *Boa sigma*, *Rena humilis*, *Storeria storerioides*, *Trimorphodon tau*, and *Micrurus proximans* were represented by only one specimen each (Figure 3c).

Herpetofauna outside of REBSSJ

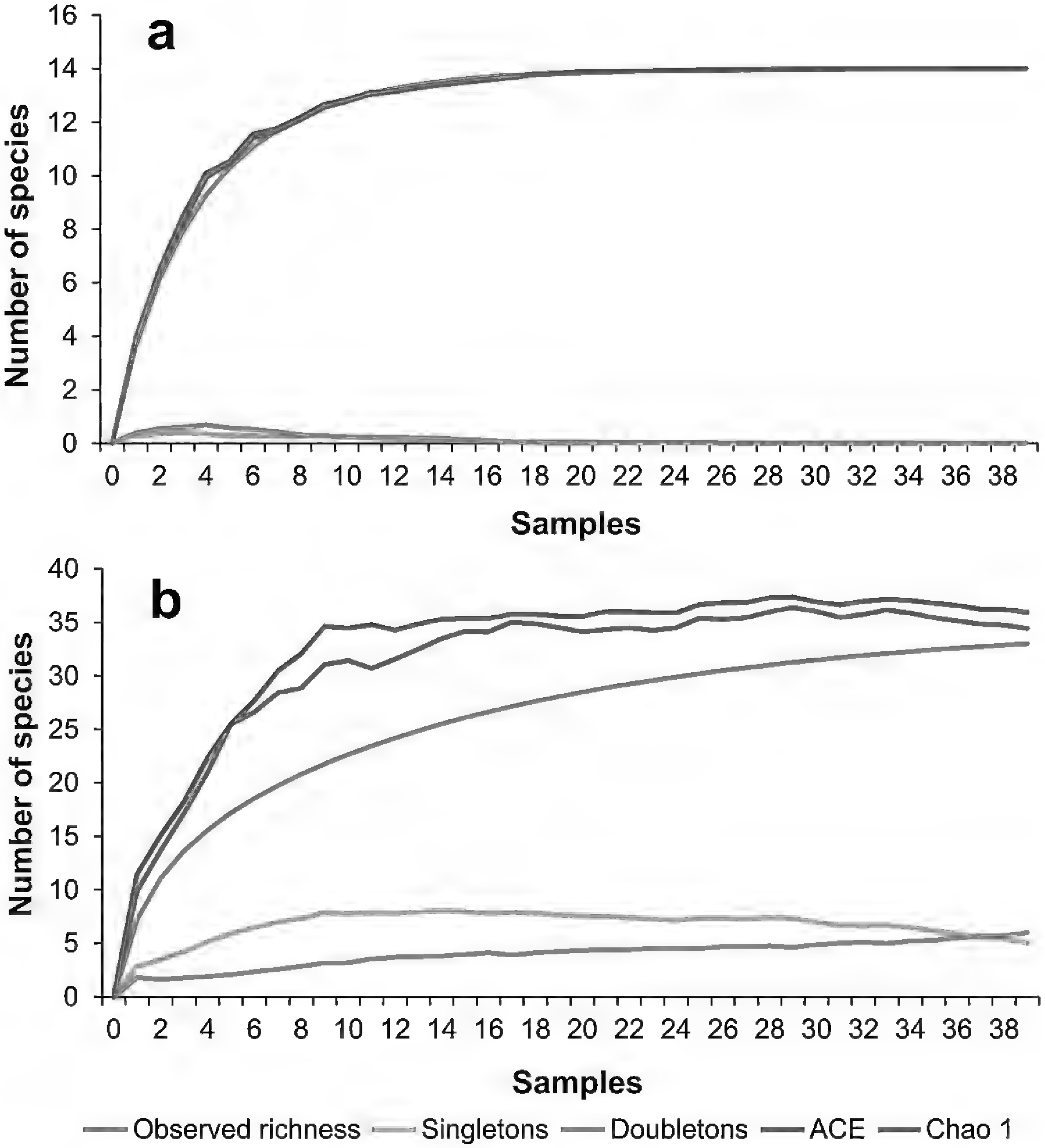

Figure 4. Species-accumulation curve of amphibians (**a**) and reptiles (**b**) outside REBSSJ. Observed richness, species represented by a single individual (singletons), species with two individuals (doubletons), and estimated species (ACE and Chao 1).

In this area we carried out 39 samplings. The species list for this area consists of 47 species (14 amphibians and 33 reptiles; Table 1). Amphibian species are represented by five families, with Hylidae the most diverse with five species (Table 1). Among reptiles, two turtle species are included in one family each (Table 1). Of 11 lizard species, four are included in the family Phrynosomatidae, and of the 20 snake species, 12 are included in Colubridae, which is the most diverse (Table 1).

Species accumulation curves, completeness of the inventory and abundance of amphibians and reptiles outside of REBSSJ

Outside of REBSSJ was recorded a total of 14 amphibian species. Non-parametric estimators ACE and Chao 1 predicted 14 species each (Figure 4a), which showed a completeness of 100%. Among reptiles, we recorded a total of 33 species, and the estimators ACE and Chao 1 predicted 35.9 and 34.4 species, respectively (Figure 4b), obtaining a completeness of 91.8 and 95.8%, respectively (Figure 4b).

Respect to abundance, in amphibians, *Exerodonta smaragdina* was the most abundant species, followed by *C. occidentalis* (Figure 3d), and the least abundant was *C. vocalis* (Figure 3d). Among reptiles, lizard species were the most abundant in this environment, with the dominant species being *A. nebulosus*, *S. utiformis*, and *Holcosus sinister*. On the other hand, *Elgaria kingii*, *H. frenatus*, and *S. melanorhinus* presented a low individual number each (Figure 3e). Among snakes, the most abundant species were *M. proximans*, *Leptodeira splendida*, and *Mastigodryas melanolomus*; in contrast, *Tantilla calamarina*, *Sibon nebulatus*, *Indotyphlops braminus*, and *Agkistrodon bilineatus* were represented by one specimen each (Figure 3f).

Beta diversity

According to the values of completeness, we observed similar values of species composition of amphibians and reptiles in both inside and outside environments. Among amphibians, the completeness value between sites was 0.60, and among reptiles 0.50, which indicates an intermediate complementarity in species composition among these environments.

Comparison inside vs. outside of the reserve

In general, a high pattern in species richness, diversity, and abundance of amphibians and reptiles was found outside rather than inside the reserve (Table 2; Figures 5 and 6a–c). The analysis of true diversity showed remarkable differences between environments; outside the reserve showed the highest values for both amphibian and reptiles (Table 2). According to species richness and abundance, outside of the reserve was found to have double of the number of amphibian species and number of individuals by species than inside the reserve (Figure 6a). This pattern was similar in snakes, where outside of the reserve we found 20 species distributed among 64 individuals, whereas inside were 14 species scattered among 30 individuals (Figure 6c). Both inside and outside of the reserve we found the same species of turtles, but outside the density was higher than inside (Table 2). Inside of the reserve, however, lizard density was higher (103 individuals) than outside, with both environments containing 11 species (Figure 6b; Table 2).

Table 2. Summary of values of diversity and abundance by taxonomic group registered inside and outside REBSSJ, Nayarit, Mexico.

Group	Total species	Species richness		Abundance		True diversity		Shared species
		inside	outside	inside	outside	inside	outside	
Amphibians	15	7	14	680	1199	2.33	9.6	6
Tortoises	2	2	2	4	8			
Lizards	14	11	11	937	834	4.42	7.96	8
Snakes	24	14	20	30	64	2.35	16.47	10
Totals	55	34	47	1651	2105			

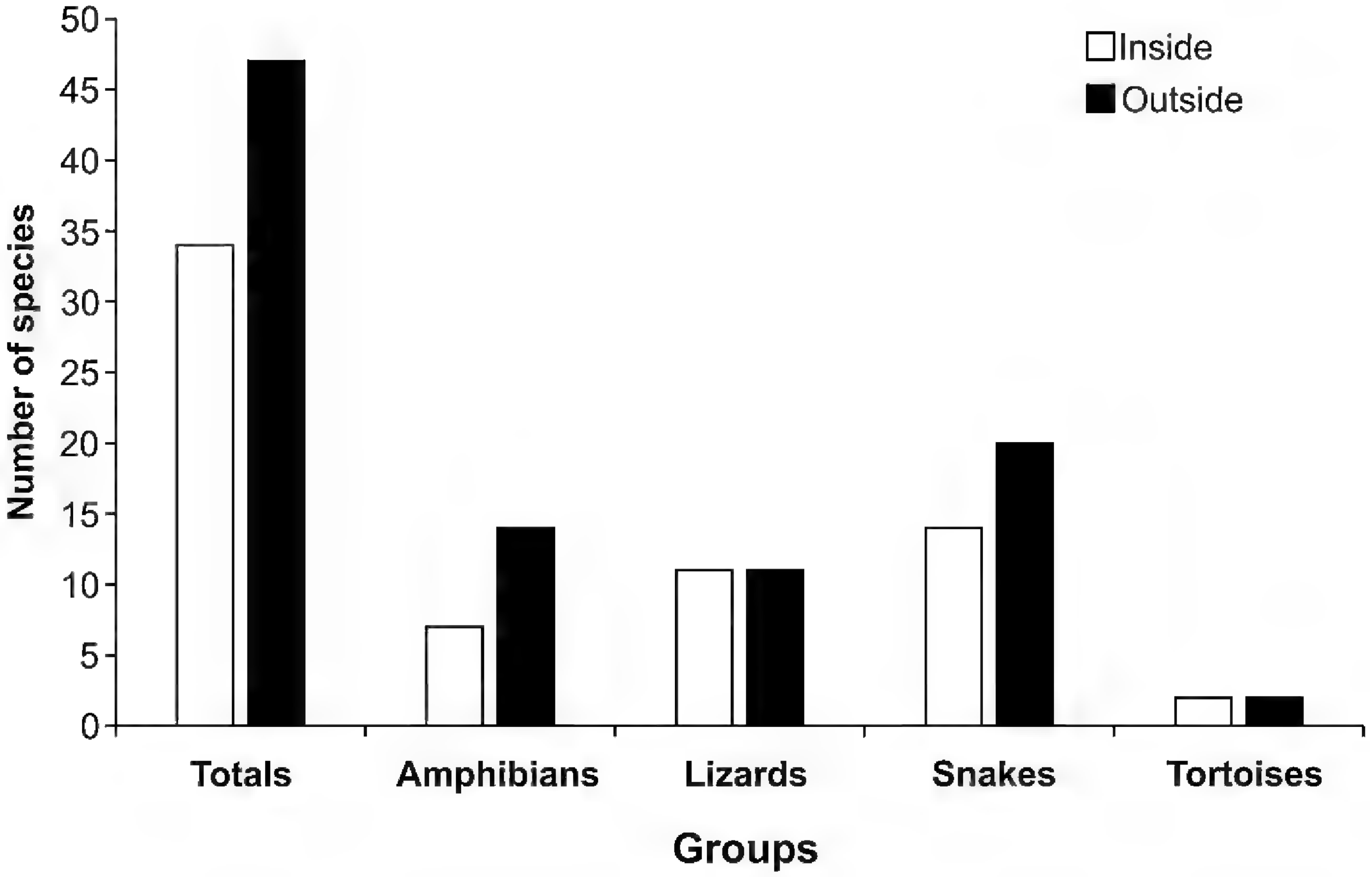

Figure 5. Graphic comparison of the number of species (total and by taxonomic group) inside and outside of REBSSJ.

Table 3. Functional richness (Fr), functional equity (Fe), and functional dispersion (Fd) of herpetofauna inside and outside of REBSSJ, Nayarit, Mexico.

	Amphibians			Reptiles		
	Fr	Fe	Fd	Fr	Fe	Fd
Inside	2.55	0.28	1.39	8.13	0.37	1.93
Outside	3.98	0.37	2.64	8.91	0.38	2.83

Functional guilds inside vs outside of the reserve

Functional richness, functional equality, and functional dispersion indices were higher for amphibians outside the reserve (Table 3). For reptiles, functional richness and functional dispersion indices were found to be higher outside the reserve (Table 3). The

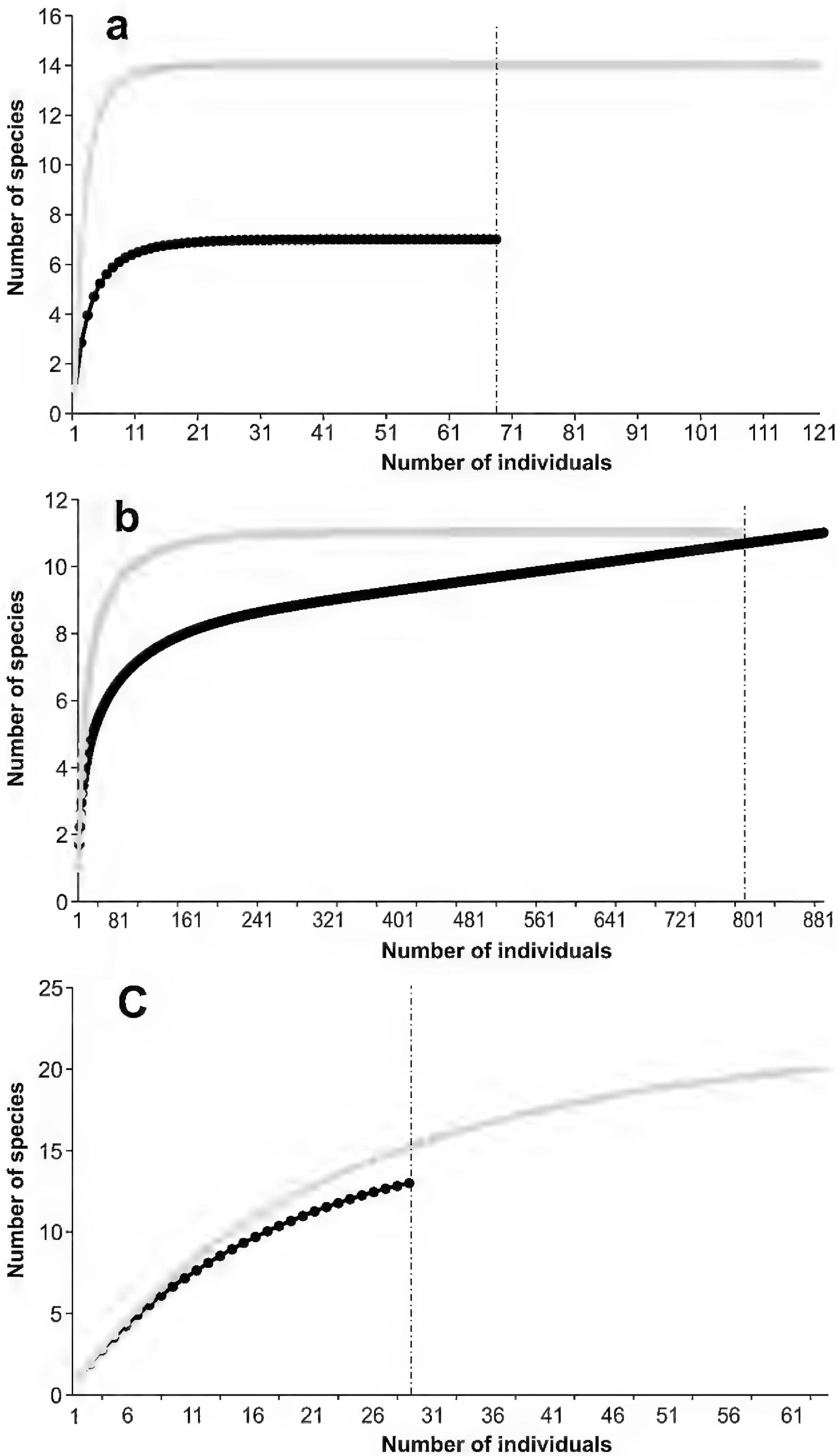

Figure 6. Rarefaction curves of species of amphibians (**a**), lizards (**b**), and snakes (**c**). Richness is compared inside black line and outside gray line of REBSSJ. Vertical line refers to the minimum number of individuals between sites.

Table 4. Number of species under different risk categories indicated by the national and international regulations (NOM-059, IUCN 2016), and environmental vulnerability index (EVS).

Normative	Category	Amphibians		Reptiles	
		inside	outside	inside	outside
IUCN	Least concern	4	11	19	21
	Vulnerable	1	1		
	Near Threatened				1
	Deficient Data	2	2		
	Not Consider			8	11
Population status (IUCN)	Decreasing	2	4	2	2
	Stable	2	6	15	17
	Increasing		1		
	Unknown	3	3	2	3
	Deficient data			8	11
Endemisms	Endemic	5	11	15	16
	No endemic				
NOM-059	Pr	2	4	8	9
	A			4	5
EVS	Low	3	5	5	11
	Medium	3	8	12	11
	High	1	1	5	7
	No evaluated			4	3

greatest contributions of richness and functional dispersion are given by the features and niches exploited by species of the genera *Sceloporus*, *Ctenosaura*, and *Hemidactylus.* Functional equity was found to be almost equal in both sites.

Protected species inside vs outside of the reserve

Outside the reserve we recorded a higher species number under some category of risk in national regulation according the NOM-059 (DOF 2010), also by the international list of the IUCN, and by using Environmental Vulnerability Score (EVS) algorithm (Table 4).

Discussion

The herpetofauna of Nayarit had been ignored for a long time (Flores-Villela et al. 2004). Currently, however, it is known that the state has 154 species, including 34 anurans, two salamanders, one crocodylian, 107 squamates, and 10 turtles (Woolrich-Piña et al. 2016). In this study we recorded for the entire Sierra San Juan a total of 55 species, representing 35.5% of the state herpetofauna. Of this number of species, the area corresponding to REBSSJ has a herpetofauna of 34 species. Woolrich-Piña et

al. (2016) mentioned that the herpetofauna of REBSSJ is composed by 73 species of amphibians and reptiles (19 anurans, 52 squamates, and two turtles). This number of species, however, was taken from the literature; only occasionally one of the authors visited the REBSSJ. Our results are the product of 39 months of fieldwork, which shows that the herpetofauna inside REBSSJ is composed of seven species of anurans, 25 squamates, and two tortoises. Our accumulation curves shows that our inventory of amphibians is complete and for reptiles between nine and 17 species are expected to be recorded in order to achieve the asymptote and completeness of the inventory. Thus, Woolrich-Piña et al. (2016) results overestimated the herpetological biodiversity inside the reserve because they did not conduct a systematic field sampling. In this sense, monitoring and field studies in natural protected area, as well as its surrounding areas represent the best strategies for documenting species richness, as well as diverse aspects of the recorded species, such as natural history, population density, and communities structure (Ervin 2003, Rodrigues et al. 2004). In addition to the bibliographic review and revision of data bases are important sources for evaluating and the decree of the natural protected areas (Ervin 2003).

Inside of REBSSJ was found a lower species number than outside of this NPA. This pattern is similar to that seen in other studies that analyzed species richness and abundance of species from different biological groups inside and outside of a NPA as mammals (Decher and Bahian 1999, Caro 2001), birds (Herremans 1998), and fungi (Bhagwat et al. 2005). In this study we recorded a remarkable increase in species richness and abundance of the herpetofauna outside the reserve. This difference could be explained by environmental heterogeneity among areas, which generates edge effect (Schlaepfer and Gavin 2001), and modification of the environment toward agro-ecosystems, such as shade coffee plantations (Pineda et al. 2005), and land-use change involving grazing areas (Gardner et al. 2007). For example, in two different studies by Bell and Donnelly (2006) and Berriozabal-Islas et al. (2017), with amphibians and reptiles in the former, and with lizard in the last; in both studies the composition of communities was different to those preserved environments. These studies found a decrease in species richness and diversity to transformed environments. These results show a remarkable difference in species richness and composition of communities among areas (Gardner et al. 2007, Berriozabal-Islas et al. 2017).

Inside the REBSSJ we recorded a lower species number of amphibian and reptiles, with *Craugastor* of the former group the dominant genus. Species of this genus are associated with temperate environments, such as pine forest and pine-oak forest, which were dominant in this area of the reserve (Meza-Parral and Pineda 2015). This pattern is promoted by the vegetation cover of the area, as shown in other studies (Urbina-Cardona et al. 2006, Cruz-Elizalde et al. 2016). Although inside the reserve there exists a higher portion of preserved forest, without apparent agricultural modification, in this area only a species of hylid frog (*Sarcohyla bistincta*) occurs; in contrast, outside of the reserve we recorded five species of hylid frogs (*Agalychnis dacnicolor*, *E. smaragdina*, *S. bistincta*, *Smilisca baudinii*, and *Tlalocohyla smithii*). These results, in the former case, might be associated with the fact that inside the reserve there are no permanents water bodies, which provide the necessary requirements for these kind of species (Wiens et al.

2006), although inside of the reserve there is a high proportion of tree coverage, mainly oak-pine forest and cloud forest (Téllez 1995) in which these species are distributed (Wiens et al. 2006, Cruz-Elizalde et al. 2016). In the latter case, the result might be due to the fact that outside the reserve there exist patches of tropical vegetation, such as semi-deciduous rainforest and cloud forest with temporary streams that provide the necessary requirements for species reproduction, and therefore, a high species diversity of this group (Pineda et al. 2005, Wiens et al. 2006). This pattern is similar to those reported for tropical environments from low elevations, where the species diversity of the family Hylidae was high (Pineda et al. 2005, Cruz-Elizalde et al. 2016).

It is well known that the NPAs are important for nature conservation (Ervin 2003). This study showed that places outside the reserve are represented by cultivated zones of mango and avocado, grazing areas, and shade coffee plantations, which maintain a high species richness and abundance for both amphibians and reptiles. In this sense it has been reported that the surrounding matrix of the protected areas plays an important role in the protection of some species (Halpin 1997, Hannah et al. 2002), in particular for those species with high mobility (Estrada et al. 1994, Caro 2001). Halpin (1997) and Hannah et al. (2002) coincide that climate change affect the structure and dynamics of the landscape, mainly in natural protected areas. These authors pointed out that due to climatic change, diverse species can change their range of migration at large scale (Peters and Darling 1985), and at local scale, their altitudinal distribution in a linear way, mainly in mountains (Peters and Darling 1985, Halpin 1997, Hannah et al. 2002), modify species composition inside and outside of reserves or preserved environments (Halpin 1997). These patterns of variation of species among areas have been tested in mammals of rain forest in Los Tuxtlas, Mexico (Estrada et al. 1994), or inside and outside of natural protected area from Tanzania (Caro 2001). Among reptiles, lizards and snakes showed two patterns in richness and abundance between sites. Lizards, both inside and outside the reserve showed similar species number (11 species); however, inside of the reserve a high number of individuals occurred than outside. In this sense, species that occurred in both inside and outside of the reserve were of the genus *Sceloporus*, which showed tolerance for the transformed environments due to physiological advantages as impermeable skin or high tolerance to aridity, use a high diversity of environments, and diversity of habits (e.g., saxicolous, arboreal; Macip-Ríos and Muñoz-Alonso 2008). These patterns have been promoted by heterogeneous environments that are reflected in a high number of microhabitats, such as logs, rocks, holes, accumulated rocks, left litter, open areas, which in turn will generate perch sites (Luja et al. 2008). These conditions are favorable to *S. utiformis* and *A. nebulosus* because they were dominant species in both inside and outside the reserve. This dominant pattern has been reported in lizard species from tropical environments (Gardner et al. 2007, Vitt et al. 2007).

Among snakes, a high number of species and individuals were found outside of the reserve. This phenomenon is explained by the high dispersal capacity of this group of reptiles, species of which have a larger home range than do lizard species (Vitt et al. 2007). In addition, most of the recorded snakes are nocturnal; therefore, the occurrence outside of the reserve might be related to the presence of water bodies, where

abundance of the amphibians is high, with these snakes feeding on this group (Cadle and Greene 1993, França et al. 2008).

Studies on fragmented tropical environments show that the transformation of environments reduces the alpha diversity, but increase the diversity at a landscape level (Vitt and Caldwell 2001). This pattern is similar to our results, because species composition for both communities (inside and outside) was complementary. For example, inside the reserve, the amphibian *C. augusti* was the exclusive species, and *Incilius mazatlanensis* and *Rhinella marina* were exclusive outside of the reserve. Similar patterns occurred in lizards and snakes; places outside the reserve had a higher number of exclusive species, such as *Drymobius margaritiferus*, *Oxybelis aeneus*, and *A. bilineatus* inhabiting tropical environments (França et al. 2008).

In addition to remarkable differences in species richness and abundance of amphibian and reptiles between sites, outside the reserve we recorded higher scores of functional diversity in both amphibians and reptiles. Such differences suggest a more complex network of interactions among the components of biodiversity outside the reserve. Outside the reserve there is a more heterogeneous landscape, which gives the species the opportunity to diversify in terms of guilds (habitat, food, or habits). Therefore, if these sites are not considered within the measures of conservation, biodiversity will be severely eroded. Finally, outside the reserve we found a major species number under some category of protection of the IUCN (2016), NOM-059, as well a high species number under the category of medium environmental vulnerability (Table 4). This reserve belongs to an important region in the context of biodiversity, because currently new forms of amphibian species have been recognized there (Caviedes-Solís et al. in preparation), which suggests that species richness for this area will increase in the future.

Our results suggest that in addition to protecting the area designated as NPA's, studies in surrounding areas should be carried out to consider the possibility of protecting a greater amount of habitat that should include semi-deciduous tropical forest and cloud forest to conserve a higher number of species (Toledo and Fernades Batista 2012). In this sense, the analyzed areas require a good programs of plans and management for conservation of the reserve and its boundaries (Herremans 1998, Caro 2001, Bhagwat et al. 2005, Becker et al. 2010).

Implications for conservation of herpetofauna in natural protected areas in tropical environments

Land use change is the main cause of the loss of diversity in the last decades (Ervin 2003, Hayes 2006), being tropical regions strongly threatened (Laurence et al. 2012). The decree of NPA´s in tropical environments is the main measures to conservation of diversity (Bruner et al. 2001, Rodrigues et al. 2004); however, effectiveness of the reserve for conservation depends of diverse factors, such as environmental heterogeneous, size of patch, and connectivity with other reserves, as land use inside and outside of the natural protected area (Juárez-Ramírez et al. 2016).

Bruner et al. (2001) evaluated the effectiveness of the natural protected areas in tropical countries with high anthropogenic threats, and recorded that most of the cases, natural protected areas fulfill conservation function, in addition to mitigation the anthropic effect. In this sense, for amphibians and reptiles is essential evaluation of the effectiveness of the NPA´s on their populations conservation and the impact of its surrounding areas (Suazo-Ortuño et al. 2015). To date there is a sufficient number of studies analyzing fragmentation effect on tropical environments (Pineda et al. 2005, Gardner et al. 2007, Macip-Ríos and Muñoz-Alonso 2008, Cruz-Elizalde et al. 2016), however, there are few studies analyzing the NPA´s, as well as the effect of surrounding matrix (Laurence et al. 2012).

Herpetofauna inside of the NPA´s have been analyzed in several studies from tropical environments of the world (Bruner et al. 2001, Bell and Donelly 2006, Gardner et al. 2007, Laurence et al. 2012), but very few in tropical environments from Mexico (Vite-Silva et al. 2010, Suazo-Ortuño et al. 2015, Berriozabal-Islas et al. 2017). These studies show a general pattern of species loss of the NPA´s toward surrounding and fragmented environments (Suazo-Ortuño et al. 2015). When comparing these results with our data, it showed a different pattern, with a higher species richness, diversity and abundancy of amphibians and reptiles outside of the NPA than inside. Species richness and diversity recorded inside and outside of the NPA´s may differ among biological groups, being more significant in vertebrate group with low vagility, such as amphibians and reptiles (Pineda et al. 2005, Berriozabal-Islas et al. 2017) than those with high movements, as mammals (Caro 2001), or birds (Herremans 1998). This response is influencing by degradation and modification of the landscape around of an NPA (Laurence et al. 2012), due to areas under protection are isolated and is generated an edge effect, and therefore, modifications in environmental parameters (e. g., temperature, solar radiation) and ecological (e. g., habitat and microhabitats availability) that affect population density (Pineda et al. 2005). Therefore, landscape modification also promotes a high number of habitats and conditions that favors a higher number of generalist species (Caro 2001, Cruz-Elizalde et al. 2016) than those occupying particular microhabitats or are in restricted to a single environmental type (Wiens et al. 2006).

Considering to the results showed in this study, where outside of the NPA is reported a higher number of species, higher functional diversity, and higher species number under high categories of conservation, we suggest the following measures to be considered in future studies that compare the herpetofauna inside and outside of an NPA´s: i) to analyze the status of conservation under different national (e. g., NOM-059), and international regulations (e.g., IUCN) of the species (Wilson et al. 2013a, b, Cruz-Elizalde et al. 2016); ii) to evaluate ecotones among areas that comprise the NPA´s and surrounding environments (Pineda et al. 2005); iii) to analyze species richness and diversity considering environmental factors, such as vegetal cover, temperature, solar radiation, and resources availability among different environments (Urbina-Cardona et al. 2006, Vitt et al. 2007), and iv) to evaluate the partition of the diversity at regional level and consider the functional and phylogenetic diversity of the communities inside and outside of the NPA´s (Cruz-Elizalde et al. 2016, Berriozabal-Islas et al. 2017).

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